Agronomic Effectiveness of Vermicompost in Grassland Systems

A Dissertation

submitted in partial fulfilment

of the requirements for the Degree of

Bachelor of Agricultural Science with Honours

at

Lincoln University

by

Paige Mary Abernethy

Lincoln University

2017

Abstract of a Dissertation submitted in partial fulfilment of the requirements for the Degree of Bachelor of Agricultural Science with Honours.

Agronomic Effectiveness of Vermicompost in Grassland Systems

by

Paige Abernethy

Vermicompost is the proccess of organic waste breakdown by red worms (*Eisenia foetida)* and other microorganisms. Vermicompost increases the bioavailability of nutrients which encourages the growth of plants and germination of seedlings, thus acting as an organic fertiliser. The objective of this trial was to assess and quantify the agronomic value of vermicompost applied to six different soils with respect to perennial ryegrass uptake of applied nitrogen, phosphorus, potassium and sulphur. The vermicompost was collected from the Tuaropaki Trust, in Mokai, along with six different soils collected from their sheep and beef farm, recently converted forestry block and dairy farm. A pot trial comparing perennial ryegrass response to vermicompost and equivalent soluble nutrients was set up at the Lincoln University glasshouse in May and was harvested in September 2017. The perennial ryegrass was analysed for dry matter yield and total nutrient uptake. Results showed, the relative agronomic performance of vermicompost at 6 and 12 t/ha was low in comparison to soluble nutrient uptake, especially for nitrogen (6-7%) and sulphur uptake (8-11%). This was suggested to be linked to the nutrients held in organic form, which was unavailable for immediate plant uptake. On the other hand, phosphorus (16-22%) and potassium uptake (25-26%) increased steadily with vermicompost application, which was associated with nutrients mainly present in inorganic forms. These trends were evident across six soils and with higher vermicompost applications of 24 to 96 t/ha. The findings of this experiment clearly demonstrated, Tuaropaki vermicompost was a relatively poor short-term source of major nutrients for perennial ryegrass compared with nutrients added in soluble form. However, Tuaropaki vermicompost could potentially be a viable slow release nutrient source and a soil conditioning agent.

Keywords: *Eisenia foetida,* organic, perennial ryegrass, Tuaropaki, soluble nutrients, slow release.

Acknowledgements

I would firstly like to acknowledge my supervisor Leo Condron for his help in establishing the pot trial and assisting me with formulating my dissertation. I would also like to thank him for taking care of the of the pots while I was away and advising me throughout the trial.

I'd like to acknowledge the help from the Tuaropaki Trust for their co-operation with the trial and funding of the nutrient analysis'. I'd like to thank them for their genorosity and allowing me to use their soil and vermicompost for the experiment.

I'd like to acknowledge my family and friends for the endless support and encouragement while I carried out this study. Especially, Eva and my sister Erin for assiting with the final editing of my dissertation.

Lastly, I'd like to thank Brent Richards at the Lincoln University Glasshouse for assiting with the pot trial and listening to my requests during the course of the experiment.

Table of Contents

List of Tables

List of Figures

1. Introduction

Vermicompost has the potential to be an important soil amendment in the agriculture and horticulture industry, as its nutrient rich nature promotes plant growth and development. The primary purpose of vermicompost is to recycle organic waste into a nutritive product which may be used to grow food again (Yadav & Singh, 2014). The mineralisation of nutrients by microorganisms and worms provides plants with a continuous source of readily available nutrients. The most common vermicompost worms are red worms, *Eisenia foetida* (Planet Natural Research, 2012). These worms consume organic solid waste, digest the material and excrete it as a stable material called vermicasts. The vermicasts are rich in nitrogen, potassium, phosphorus and many micronutrients.

Fertiliser is commonly applied to agricultural and horticultural systems to increase and maintain pasture and crop yields. However, fertiliser use may serve as a risk to human health and the environment (Joshi et al. 2015). If nitrogen concentration in groundwater exceeds the world health organisation's recommendation for safe drinking limits, lakes can become eutrophic and infants are at risk of methemoglobinemia (Di & Cameron, 2000). Vermicompost is produced as an alternative to fertiliser to improve plant growth while not at the expense of the environment. Moreover, vermicompost may also be produced as a disposal option for various organic wastes. Current waste disposal options include burial and burning which are harmful to the environment. However, 50-60% of the waste buried consists of organic waste material which is highly valuable for vermicompost (Hossein et al. 2017).

Vermicompost is a useful plant growth amendment due to the increased bioavailability of nutrients from mineralisation, which encourages high germination and dry matter production of plants (Sabrina et al. 2013; Atiyeh et al. 2000; Bajracharya et al. 2007; Chavda & Rajawat, 2015). Further research should explore the influence of applying vermicompost on pastoral systems. The objective of this trial was to assess and quantify the agronomic value of vermicompost applied to six different soils with respect to perennial ryegrass uptake of applied nitrogen, phosphorus, potassium and sulphur.

2. Review of Literature and Research Objectives

2.1. The production of vermicompost including inputs

2.1.1. Mineralisation by microorganisms

Vermicompost is living organic material produced through the mutual association of microorganisms and worms. Vermicompost produces readily available nutrients for plants due to microbial activity within the compost. Through the process of mineralisation, microorganisms in vermicompost release nutrients into plant available form which are essential for the growth of plants. Bacteria and fungi initiate this process, mineralising large amounts of organic material (Condron, 2017). Mineralisation is greatly enhanced by other organisms grazing on the bacteria and fungi (Parfitt et al. 2004). Red worms (*Eisenia foetida*) graze on these microorganisms and turn over large areas of vermicompost through bioturbation. Nematodes contained in the vermicompost also influence mineralisation and immobilisation. Griffiths (1986) study found, the nitrate concentration was increased by 0.286 µg N g^{-1} in the rhizosphere after the introduction of nematodes.

The red worms (*Eisenia foetida*) process the vermicompost by shredding the organic material into finer fragments which increases the surface area exposed to microorganisms (Orgiazzi & Bardgett, 2016). This accelerates mineralisation by the microbes, converting a great quantity of the nutrients held in the vermicompost into plant available form. Red worms *(Eisenia foetida)*, consume each layer of vermicompost, and excrete vermicasts which are rich in bioavailable nutrients. Once the material is broken down, it's spread across fields to amend crop and soil health as an organic fertiliser or as an alternative source of energy (Singh et al. 2015).

2.1.2. Role of *Eisenia fetida,* in nutrient turnover

The red worms improve the quality of the vermicompost via fragmenting and aerating the material whilst breaking down organic matter into vermicasts. Typically, 2 kilograms of red worms can convert 1 kg of organic waste into nutrient rich material each day (Yadav & Singh, 2014). Approximately 5-10% of the material consumed by the Eisenia fetida is absorbed in the body, while the remaining 90-95% is excreted as mucus coated vermicasts. (Hossein et al. 2017). Moreover, the vermicasts contain immobilised enzymes such as lipase, amylase and protease, which encourages further microbial attack from other microorganisms (Yadav & Singh, 2014).

The material is mineralised in the gut of the worm where organic carbon is reduced by 8-24% (Hossein et al. 2017). The degree of mineralisation is affected by moisture, temperature and pH of the vermicompost (Orgiazzi et al. 2016). The size of the worms may also influence how much material is processed, as the smaller worms feed primarily on litter, whereas larger worms consume and produce larger amounts of organic material (Singh et al. 2011). The outer mucus coating of the casts are hygroscopic, which improves the water holding capacity of the vermicompost, as these casts absorb water (Ievinsh, 2011). The vermicasts also contain worm cocoons allowing the continuous production of worm species (Yadav & Singh, 2014). Consequently, worms may regenerate at a constant rate so there is always a large population in the vermicompost to effectively break down organic material. If the conditions of the vermicompost are good, the worm population will increase until the food is limiting (Nidoni & Math, 2015).

The vermicasts excreted by red worms (*Eisenia fetida),* contain a high level of plant utilisable nutrients and plant growth regulators. The nutrients excreted in the vermicasts stimulate microbes for further microbial attack, thus the mineralisation of organic waste is accelerated (Tejada & Gonzalez, 2009). A study based on the performance of vermicompost on groundnut and cotton yield, found the application of vermicompost encouraged early growth of seedlings (Chavda & Rajawat, 2015). The vermicompost also improved root length and stem elongation due to the increased supply of nitrate, exchangeable phosphorus, soluble potassium, calcium and magnesium present in the organic material. Consequently, at 5 t/ha of vermicompost, the yield was increased by 14.98% for both groundnut and cotton compared to the control pots (Chavda & Rajawat, 2015). This was consistent with Kizilkaya, et al. (2012) findings, as vermicompost application on wheat showed positive effects on grain and straw yield due to the nutrient supply of the material (Table 1).

Table 1. Analysis of vermicompost addition on the grain and straw yield (10^3 kg ha^{-1}) and nutrient uptake (%) of wheat in Turkey (Kizilkaya et al. 2012)

Parameters	Control	1	2	3	4	5	6
Vermicomposted organic wastes (OW)							
Grain yield, 10^3 kg ha^{-1}	3.23	3.81	4.22	4.66	5.22	5.54	6.27
Straw yield, 10^3 kg ha^{-1}	15.8	16.9	18.5	19.3	21.6	24.6	26.6
N in grain, %	1.85	1.76	1.76	1.80	1.81	1.80	1.66
N in straw, %	0.34	0.39	0.41	0.43	0.46	0.48	0.49
N in soil, %	0.14	0.17	0.17	0.18	0.18	0.18	0.20
P in grain, %	0.41	0.44	0.49	0.44	0.46	0.49	0.49
P in straw, %	0.06	0.16	0.18	0.20	0.23	0.26	0.28
P in soil, mg kg^{-1}	40.4	48.8	50.6	52.3	55.2	61.5	72.1
K in grain, %	1.20	1.36	1.45	1.54	1.66	1.75	1.86
K in straw, %	1.54	1.74	2.16	2.34	3.06	3.00	3.38
K in soil, cmol(+) kg^{-1}	5.53	9.04	7.62	6.97	6.32	5.89	5.39
Not vermicomposted OW							
Grain yield, 10^3 ha^{-1}	3.23	3.53	3.87	4.15	4.69	5.14	5.27
Straw yield, 10^3 ha^{-1}	15.8	15.7	17.4	18.6	19.6	20.1	23.0
N in grain, %	1.85	1.79	1.75	1.88	1.83	1.82	1.80
N in straw, %	0.34	0.36	0.36	0.37	0.38	0.42	0.43
N in soil, %	0.14	0.15	0.15	0.17	0.17	0.17	0.18
P in grain, %	0.41	0.42	0.42	0.39	0.41	0.37	0.44
P in straw, %	0.06	0.13	0.17	0.18	0.21	0.23	0.25
P in soil, mg kg^{-1}	40.4	45.7	52.5	52.4	50.3	57.8	58.0
K in grain, %	1.20	1.29	1.32	1.3	1.42	1.44	1.47
K in straw, %	1.54	2.06	2.13	2.39	2.35	2.82	2.74
K in soil, cmol (+) kg^{-1}	5.53	9.37	8.44	7.62	7.18	6.43	6.12

Table 1 demonstrates the overall increase of nitrogen, potassium and phosphorus levels in the vermicompost treatment. This subsequently raised the wheat straw yield in all plots, especially the vermicompost treatments of 40% sewage sludge and 60% hazelnut husk (plot 5). In this plot, the straw yield was higher than the control. In this study, vermicompost acted as a slow release fertiliser, supplying the soil and plants with valuable nutrients which elevated grain and straw wheat yields. The amount of vermicompost processed by the worms is dependent on the availability of suitable organic waste for consumption (Nidoni & Math, 2015).

2.1.3. Vermicompost inputs

Organic wastes used in the production of vermicompost may consist of green waste, sewage sludge and milk sludge. Other sources of inputs have been trialled including grape pulp, seaweed, septic tank sludge, paper waste and other nutrient rich alternatives. Sawdust is another source of waste, which is incorporated in to the vermicompost as a bulking agent to assist in the retention of leachate (Tejada & Gomez, 2015). The inputs are collected from various sectors and are arranged in layers in a random sequence. Temperature of the vermicompost must be kept below 25°C to prevent worm fatality (Orgiazzi & Bardgett, 2016). Thus, inputs may require pre-composting to bring the temperature down. This is especially important in trials involving vermicomposting of septic tank waste, as E-coli pathogens contained in the waste are of higher temperatures, beyond what the red worms may tolerate. Therefore, pre-pasteurisation is required to breakdown the E-coli pathogens (Singh et al. 2011). Moreover, vermicompost beds should be kept moist at 50% moisture content and machinery may be required to break down raw materials (Nidoni & Math, 2015). Vermicompost may consist of wastes from many different sources. However, the material used in vermicompost must be of organic origin, contain no sharp items and be within the range of temperatures the worms can tolerate. There are many sources of organic waste produced on farm which may be suitable for vermicompost, thus it may act as waste disposal option.

2.1.4. Mitigation of on farm wastes

The reliance of mineral fertilisers and the mass discharge of livestock manure in agriculture has led to high levels of environmental pollution. Currently, majority of wastes are removed by burial or burning. These methods are time consuming and pollutes the water and soil (Hossein et al. 2017). However, 50-60% of the waste buried consists of organic waste material which is highly valuable for vermicompost. Vermicompost is a strategy to transform wastes produced on farm into valuable compost (Guo et al. 2015). Vermicompost can be referred to as a “circular metabolism” as it returns and recycles nutrients lost in waste, back into the soil-plant system to grow food again (Yadav et al. 2014). Moreover, the cost of disposing farm wastes in landfill sites is expensive. A large vermicompost unit, The Grace Keller Centre in Geelong, Australia are saving $56,000 per year by avoiding landfill tipping fees (Yadav et al. 2014). Vermicompost is an ideal management practice which should be implemented on farms as an organic waste disposal option.

2.2. The use of vermicompost in agriculture and horticulture including its relative agronomic value

2.2.1. Increased rate of germination

Vermicompost encourages early germination due to the increased supply of nutrients and an improvement of the environments physical conditions. A glasshouse experiment, compared the effect of applying varying rates (0-12%) of vermicompost extracts (teas) on tomato and lettuce seedlings (Arancon, 2012). It was found, the seedlings germination rate increased considerably, even at 1% concentration of vermicompost (Figure 1).

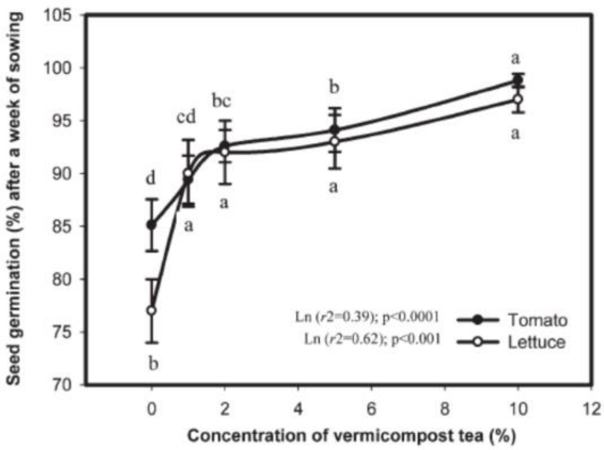


Figure 1. Seed germination (%) of tomato and lettuce as affected by soaking seeds in vermicompost tea (0-12%) for 9 hours (Arancon, 2012).

As represented in Figure 1, soaking the lettuce and tomato seedlings in vermicompost significantly improved seed germination after one week (P<0.0001). The high, early germination rate was linked to the greater nutrient content contained in the vermicompost, (NO_3-N; 137.9 mg L^{-1}, P; 11mg L^{-1}, K 45.1 mg L^{-1}, Ca; 59.6 mg L^{-1}) (Arancon, 2012). However, as the trial was conducted in a glasshouse, it reduced the validity of the trial as the plants respond differently when exposed to varied climatic conditions. Ievinsh (2011) study had similar results, as two cultivars of celery which typically had a germination percentage of 0 and 3%, showed increased germination of 7 and 13% when vermicompost extract was applied. This was associated with the improvement of soil conditions and increased availability of mineral nutrients after vermicompost application. The early emergence of seedlings is beneficial as it may encourage suppression of weeds and strong initial growth.

2.2.2. Increased canopy cover

Vermicompost may increase the leaf area and canopy size of leaves which consequently increases photosynthetic potential and yield. Vermicompost contains a high amount of nitrate which may move to the growth areas of the plant and increase the leaf area index. This in turn can increase the absorption of light, enabling the plant to undergo photosynthesis. This leads to a dry matter yield increase in plants. Papathanasiou, et al. (2012) compared applications of fertiliser and compost on the yield of lettuce. It was found, the highest leaf number (23.67) was recorded in the 10% vermicompost treatment and highest leaf dry weight (7.8 g) in the 20% vermicompost treatment. This is consistent with Uma and Malathi (2009). In this study, Amaranthus chlorophyll content increased 2.3-fold after germination following vermicompost application. This increased the yield and plant metabolism of Amaranthus plants. Similarly, leaf size of parsley plants increased following the application of vermicompost (Peyvast et al. 2008) (Table 2).

Table 2. Growth characteristics of parsley (Petroselinum crispum) grown in different applications of soil and cattle manure vermicompost in a trial in Iran (Peyvast et al. 2008).

Vermicompost: soil	Plant height (cm)	Leaf fresh weight (g)	Root fresh weight (g)	Leaf dry weight (g)	Root dry weight (% FM)
0:100	21.56c[Z]	44.8b	4.04d	4.73b	8.47a
10:100	24.83a	61.73a	6.76a	6.02a	8.43a
20:100	22.80b	35.06c	6.57b	6.42a	5.55b
30:100	21.76c	21.53d	6.40c	6.78a	3.86c

[Z]values in a column followed by the same letter are not significantly different, $P \leq 0.01$, Duncan multiple range test.

As represented in Table 2, vermicompost increased leaf dry weight (6.02g, 6.42g and 6.78g) when applied at different rates compared to the control (4.73g) (Peyvast et al. 2008). The increased leaf dry weight improved the absorption of light. However, there was no evidence to suggest the increased leaf canopy improved the plant dry weight in this study. This could have been a result high levels of salt in the vermicompost, which caused plant toxicity when applied at high levels.

2.2.3. Shoot and root elongation

Crops supplied with vermicompost may have strong early development due to increased supply of nutrients. Vermicompost contains high availability of nitrate and potassium, allowing ready absorption of nutrients and shoot elongation. Vermicompost may encourage strong initial growth of seedlings by enhanced root formation, elongation of stem and production of biomass (Chavda & Rajawat, 2015). Azarmi et al. (2009) assessed the effect of applying vermicompost on two cucumber cultivars. Stem dry weight significantly increased (30.99 g/plant and 36.06 g/plant) following the application of 30t/ha of vermicompost, compared to the control (23.31 g/plant and 27.25 g/plant).

Similarly, Bajracharya, et al. (2007) found, application of vermicompost in combination with fertiliser, increased the shoot dry weight of soybean (Table 3).

Table 3. Effect of vermicompost, rhizobium and fertiliser on grain and straw yield, nodules and root and shoot dry weight (g/plant) of soybean in Nepal (Bajracharya et al. 2007).

Symbol	Treatment Descriptionl	Grain yield (kg/ha)	Straw yield (kg/ha)	Number of nodules per plant	Root dry weight (g/plant)	Shoot dry weight (g/plant)	Nodules dry weight (g/plant)
Ct	Control	569.33	2153	249	2.43	11.23	0.42
RI	Rhizobium (800 g/ha)	611.0	2486	85.7	3.765	13.09	0.96
CF	NPK (60 : 40 : 30 kg/ha)	500.0	2597	63.3	3.275	12.98	0.45
RICF	Rhizobium + NPK	666.7	2347	45.3	2.857	12.16	0.23
VC	Vermicompost	753.0	3383	145.3	2.65	12.3	0.557
VCRI	Vermicompost + Rhizobium	698.0	3375	38.7	3.42	11.64	0.287
CFVC	NPK + Vermi compost	617.0	3025	135	3.64	13.38	0.510
RICFVC	Rhizobium + NPK + Vermicompost	667.0	3305	112	3.17	17.11	0.87
	F test	Ns	Ns	*	Ns	Ns	Ns
	Probability	0.469	0.569	0.039	0.5718	0.379	0.09
	Sed	111.2	643.25	56.53	0.6174	2.3794	0.2425
	CV%	21.4	27.7	63.3	23.5	22.5	55

Note: Ns = non significan , * = significant at p=0.05, Sed = Stadndard error of difference

The highest shoot dry weight was found under the vermicompost and fertiliser treatment (13.38 g/plant). Whereas, the lowest shoot dry weight was found in the control treatment (11.23 g/plant) (Bajracharya et al. 2007). In this trial, the shoot and root dry weights were lower under vermicompost applied alone (12.3 g/plant and 2.65 g/plant) compared to applying fertiliser alone (12.98 g/plant and 3.3 g/plant). Suthar (2009) study contrasted these findings, as his study revealed, after application of 15 t/ha of vermicompost, the yield of garlic plants was significantly increased compared to application of fertiliser. Leaf length was 0.6% higher, shoot dry weight was 31.4% higher and root length was 74.6% higher compared to mineral fertiliser application (Suthar, 2009). These contrasting results were linked to the amount of available nutrients contained in the different vermicomposts. This will vary depending on the inputs included in the vermicompost.

2.2.4. Effect of vermicompost on dry matter production

Application of vermicompost can accelerate pasture production due to the increased supply of nutrients. This may encourage early establishment and greater root growth to increase the plants access to nutrients. Sabrina et al. (2013) assessed the effectiveness of phosphorus enriched vermicompost on the DM production of Setaria grass (Table 4).

Table 4. Effect of combination of phosphate rock, oil palm, earthworm, arbuscular mycorrhizae and P-enriched vermicompost on changes in 0.5 M NaOH extractable P(ΔP), P uptake (ΔP) and plant available P (ΔP) in soil in Malaysia (Sabrina et al. 2013).

Treatment	ΔP	ΔP_s	ΔP_b
	mg P kg^{-1}		
GPR	49.67 b	11.6 b	1.8 a
EFB+ GPR	63.33 b	28.2 b	3.2 a
PEV	45.67 b	57.8 a	5.2 a
W+AM+EFB+GPR	129.67 a	26.9 b	4.4 a

Abbreviations: AM= arbuscular mycorrhizae; EFB= oil palm empty fruit bunch; GPR= gafsa phosphate rock; PEV = P-enriched vermicompost; W= earthworm. Means with the same letters in each column are not significantly different at P=0.05 level (Duncan's multiple range test).

As shown in Table 4, the plant uptake of P (57.8 mg P kg) and availability of P (5.2 mg P kg) was considerably higher in the vermicompost treatment than the other forms of plant amendments. This led to an increased root mass of 163 cm and subsequently increased DM yield (5.75 g pot to 6.46 g pot). Further investigation is needed to explore the influence of vermicompost on pastoral yield. Many researchers have studied the effects of vermicompost on various crops (Atiyeh et al. 2000; Bajracharya et al. 2007; Chavda & Rajawat, 2015). However, these studies haven't assessed the effect on pasture uptake and production. The influence of vermicompost applied to perennial ryegrass will be quantified in the current study.

2.2.5. Reduction in plant toxicity and deterrence of pests

Vermicompost can improve crop yield due to the reduction of plant toxicity and deterrence of insects. Phytotoxicity is a plant injury inflicted by compounds added to the soil, such as phenolic acid. This often occurs when chemicals are applied to regulate growth or fertilise plants (Ievinsh, 2011). Vermicompost however, produces a stable product and reduces phenol acids in the waste material. A recent study (Masciandaro et al. 2010) assessed the ability of worms to reduce phenolic compounds, and found they decreased the phytotoxicity by 50%. This increased germination by 70% under vermicompost addition compared to 43% germination in the conventional compost. In addition, other literature suggests the presence of phenolic compounds provides a benefit to plant growth, as it acts as a deterrent to pests. Edwards et al. (2002) research found aphid populations were supressed in vermicompost treated tomato and cucumber plants. Twenty-five aphids were released in each treatment and after two weeks, the population increased up to 40 in the control. Whereas, in the 20% substituted vermicompost treatment, the populations continually decreased over the next 14 days, reducing the overall damage to the crops. Consequently, there were significant increases in shoot weight and leaf area of tomato plants (Figure 2).

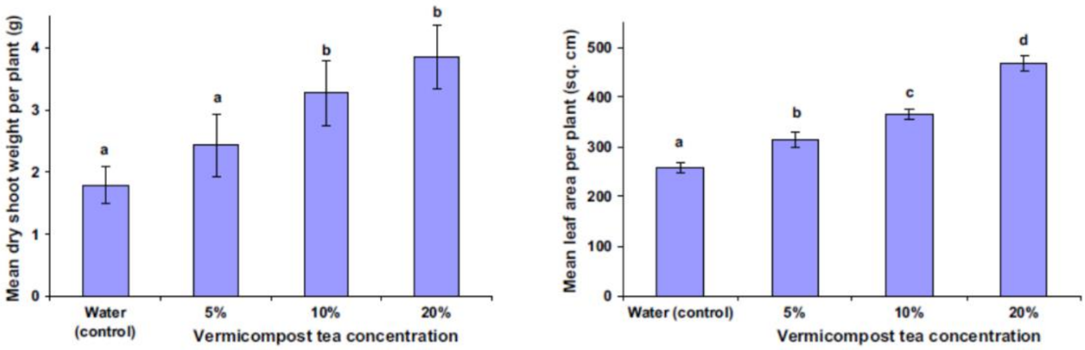


Figure 2. Effect of vermicompost tea application (5-20%) on shoot dry weight (g) and leaf area (cm^2) of tomato plants in a glasshouse trial in Ohio, USA (Edwards, et al. 2010).

As represented in Figure 2, shoot dry weight (3.8 g 20% vermicompost) and leaf area (470 cm^2 20% vermicompost) increased once vermicompost concentration increased in comparison to the control (1.8 g and 270 cm^2). This was linked to the reduction in aphid populations, encouraging optimal plant growth once vermicompost was applied at high rates. The trial suggested, the decrease in pest populations was likely due to the presence of water soluble phenolic compounds, present in the vermicompost which make plants less attractive to pests (Edwards et al. 2010).

2.2.6. Effect of plant growth regulators on crop growth

The plant growth hormones released in the vermicasts improves plant growth and yield. Vermicompost contains growth promoting substances, including auxin up to a rate of 400 ng per worm, per day (Ievinsh, 2011). Other plant hormones contained in the vermicompost include gibberellin and cytokinin. Guo et al. (2015) study compared the effect of traditional compost and vermicompost on maize yields. The final above ground biomass was higher by 7.7% in the vermicompost treatment compared to conventional compost, as shown in the figure below (Figure 3).

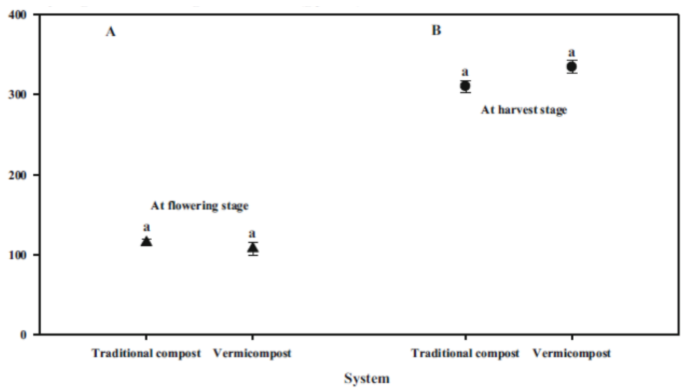


Figure 3. Dry weight of total aboveground biomass (g $plant^{-1}$) of maize plants before and after flowering with treatment of traditional compost or vermicompost (Guo et al. 2015).

As illustrated in figure 3, the aboveground biomass was higher in the traditional compost at the flowering stage by 7.1%. Results suggested, this could have been linked to the traditional compost material containing more nutrients than the vermicompost at the commencement of the study, deterring the validity of the trial. Whereas, the yield of maize was higher at the final harvest in the vermicompost treatment compared to traditional compost (Figure 3). The higher aboveground biomass in the vermicompost treatment was suggested to be linked to the large presence of plant growth hormones, while there was none present in the traditional compost. Thus, the study found, the presence of plant growth regulators led to plants being able to fully utilise the nutrients supplied in the soil. Consequently, the aboveground biomass of maize was higher at harvest stage in the vermicompost treatment. Plant yield may be further improved when vermicompost is applied in combination with fertiliser.

2.3. Effect of vermicompost combined with fertiliser

Application of vermicompost in combination with mineral fertilisers can also be of economic benefit. Nutrients contained in the vermicompost, may not match the requirements of the plant. Supplementing vermicompost with mineral fertiliser may lift nutrient levels which are lacking in the organic material. Bajracharya et al. (2007) study on the effect of vermicompost in combination with bacteria and mineral fertilisers on soybean found applying amendments together showed increase in shoot and root dry weight (Figure 4).

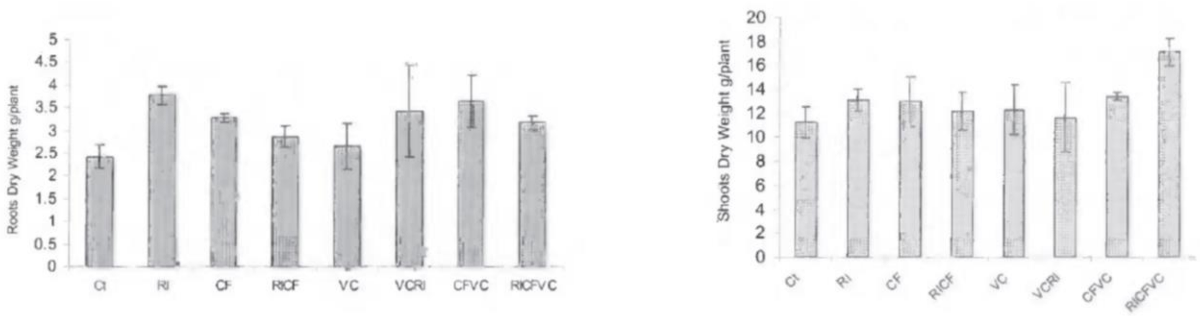


Figure 4. Effect of soil amendments (Ct: control, Rt: rhizobium inoculant, CF: chemical fertiliser, RCF: rhizobium and fertiliser, VC: vermicompost, VCR: vermicompost and rhizobium, CFVC: fertiliser and vermicompost, RCFVC: rhizobium, fertiliser and vermicompost) on vegetable soybean root (a) and shoot (b) dry weight (g/plant) (Bajracharya et al. 2007).

Despite vermicompost treatment applied alone reaching the highest yield for the soybean crop, the total root dry weight peaked when vermicompost was applied in combination with fertiliser. The root dry weight reached 3.64 g/plant when vermicompost was applied with a fertiliser (Figure 4). Thus, the research suggests vermicompost alone may give the highest overall yield, however to achieve higher root and shoot dry weight, vermicompost should be applied in combination with fertiliser for best results.

The objective of this study was to assess and quantify the agronomic value of vermicompost applied to six different soils with respect to uptake of applied nitrogen, phosphorus, potassium and sulphur, compared with water soluble nutrients.

3. Materials and Methods

3.1. Soils and vermicompost

The soils and vermicompost were sourced from Tuaropaki Trust, Mokai in March 2017. Tuaropaki Trust was established after their loan was approved in 1952. Since then, the trust has diversified their business in several different sectors. Tuaropaki have established their own geothermal power plant which produces 113 MW of electricity. This provides a power source for their other sectors. Tuaropaki also own a sheep and beef and dairy farm which is spread across 3,410 hectares. The manure produced on the dairy farm is used as an input for their vermicompost unit. The milk produced is processed at Miraka Limited. Miraka limited is situated on Tuaropaki land, which produces quality milk powder for international markets. Miraka uses the renewable electricity from Tuaropaki geothermal unit and the milk powder waste is used to produce vermicompost. Moreover, two glasshouses (6.2 ha and 5.5 ha) were established for tomatoes and capsicum production using hydroponics. The green waste and unwanted produce is another input used in the vermicompost unit. The sustainable unit comprises of large vermicompost rows where the organic waste is delivered. The organic wastes are layered in random order and the worms, *Eisenia foetida* process each layer until all layers are decomposed. More information on Tuaropaki can be found on their site www.tuaropaki.com.

3.1.1. Soils

Soil was collected from six different sites across the property. The soil was sourced in areas varying in nutrient availability, age and previous land management. Soil was sourced from the dairy effluent block, the new established dairy block, dry stock sheep and beef farm and from a newly established sheep and beef paddock. Lastly, soil was also sourced from their recently converted forestry area. Aerial photographs of the sites are pictured below (Figure 5).

Figure 5. Aerial images of Tuaropaki where soil samples were collected.

The soil was sampled and analysed by Hill Laboratories prior to the commencement of the trial. The analysis of each soil is displayed on the following page (Table 5).

Table 5. Selected chemical and physical properties of the six Tuaropaki soils.

	Measure	Control	Dairy effluent	Dairy new	Sheep finishing	Sheep new	Pine
pH	pH units	5.9	6.5	5.6	5.9	5.7	5.7
Olsen P	mg/L	2	64	130	21	51	2
Anion storage capacity	%	<15	31	30	39	48	70
Potassium	me/100g	0.63	0.71	0.6	0.31	0.85	0.35
Calcium	me/100g	<0.5	18.7	5.1	11.2	8.1	1.3
Magnesium	me/100g	<0.04	2.43	0.59	1.03	1.56	0.24
Sodium	me/100g	0.07	0.3	0.13	0.2	0.09	0.07
Cation exchange capacity	me/100g	3	28	17	24	25	12
Total base saturation	%	35	80	37	53	43	17
Volume Weight	g/mL	0.76	0.54	0.7	0.54	0.53	0.65
Sulphate Sulphur	mg/kg	12	12	13	14	15	43
Extractable Organic Sulphur	mg/kg	<2	8	5	5	6	4
EC (in 1:5 Extract)	mS/cm	<0.01	0.14	0.03	0.04	0.05	<0.01
Anaerobically Mineralisable N	µg/g	13	236	171	231	133	29
Mineral N (sum)	mg/kg	2	63	11	18	20	3
Total Carbon	%	0.1	8.3	7.7	8.3	7.5	3.3
Total Nitrogen	%	<0.04	0.79	0.61	0.72	0.53	0.22
C/N Ratio		6.1	10.6	12.6	11.5	14.1	15.1
Anaerobically Mineralisable N/ Total N ratio	%	5.7	3	2.8	3.2	2.5	1.3
Total phosphorus	mg/kg	149	2130	1636	1123	1012	223
Total sulphur	mg/kg	<45	989	775	844	617	414

3.1.2. Vermicompost

Vermicompost was sourced from the Tuaropaki sustainable unit in Mokai. The vermicompost is comprised of green waste from the glasshouses and cattle manure from the Tuaropaki dairy farm. The vermicompost also includes DAF sludge, which is a waste product created during the drying process of milk powder production. This organic waste material is delivered to the sustainable unit and kept in holding pens until it is ready to be spread on the vermicompost rows. The red worms, *Eisenia foetida,* ingest the organic material and excrete it in their waste, called vermicasts. This continues until all the vermicompost has been processed and is ready for spreading onto the Tuaropaki farms. A representation of the vermicompost rows is pictured below.

Figure 6. Vermicompost unit at Tuaropaki, Mokai

A representative sample was collected from the vermicompost rows. One kilogram of vermicompost was sent to Lincoln University for the commencement of the glasshouse trial. A subsample of the vermicompost was sent to Hill Laboratories for analysis of total nutrient content (Table 6).

Table 6. Analysis of total nutrients and pH of vermicompost sourced from Tuaropaki.

	pH	Total C	Total N	Total P	Total K	Total S	Ca	Mg	Na
Vermicompost	7.6	17.5	1.36	0.63	0.29	0.32	2.64	0.28	0.09

The vermicompost sample was also sent to Hill Laboratories to undergo analysis as a soil sample. The chemical properties of the vermicompost is indicated below (Table 7).

Table 7. Selected chemical properties of Tuaropaki vermicompost

Analysis	Measure	Control
pH	pH units	7.4
Olsen P	mg/L	247
Potassium	me/100g	5.9
Calcium	me/100g	43.2
Magnesium	me/100g	7.72
Sodium	me/100g	1.91
Cation exchange capacity	me/100g	59
Total base saturation	%	100
Volume Weight	g/mL	0.57
Sulphate Sulphur	mg/kg	326
Anaerobically Mineralisable N	μg/g	227
Total Carbon	%	12.2
Total Nitrogen	%	1.17
C/N Ratio		10.5
Anaerobically Mineralisable N/ Total N ratio	%	1.9
Total Phosphorus	mg/kg	6,100
Total Sulphur	mg/kg	3,230

3.1 Glasshouse pot trial

3.2.1. Vermicompost and nutrient rates

Two rates of vermicompost (VCM) application were selected for assessment: 6 and 12 tonnes fresh weight per hectare, which was applied to all six soils. These rates were compared to equivalent quantities of water-soluble macronutrients (N, P, K, S) applied as a combination of ammonium nitrate (NH_4NO_3), ammonium dihydrogen phosphate ($NH_4H_2PO_4$), potassium sulphate (K_2SO_4) and ammonium sulphate ($(NH_4)_2SO_4$). These quantities are represented in Table 8.

Table 8. Quantities of vermicompost and nutrients (N, P, K, S) applied to soils in the glasshouse experiment.

	6t VM FW/ha	12 t VM FW/ha

g FW/pot	4.7 g	9.4 g
kg N/ha	134*	68*
kg P/ha	16*	32*
kg K/ha	7*	14*
kg S/ha	8*	16*

*equivalent quantities of water soluble N, P, K, S applied as 3 mls (6 t VM) and 6 mls (12 t VM) of nutrient solution (14.82 g/L $NH_4H_2PO_4$, 18.41 g NH_4NO_3, 4.23 g/L K_2SO_4, 5.6 g/L $(NH_4)_2SO_4$).

In addition, higher rates of vermicompost were added to one soil (Pine), which were compared with soluble nutrient equivalents added at 6 and 12 tonnes of vermicompost per hectare (Table 9).

Table 9. Quantities of vermicompost and nutrients (N, P, K, S) applied to Pine soil in the glasshouse experiment.

	Kg/ha				
t FW/ha	**g FW/pot**	**N**	**P**	**K**	**S**
6	4.7	34	16	7	8
12	9.4	68	32	14	16
24	18.8	136	64	28	32
36	28.2	204	96	42	48
48	37.6	204	128	56	64
60	47	340	160	70	80
72	56.4	408	192	84	96
96	75.2	544	256	112	128

The experiment was conducted at Lincoln University between May and September 2017. Firstly, the control soils were weighed at 375 g per pot and lined with filter paper. The small dose vermicompost pots received 250 g of soil and 19 g of vermicompost combined in 100 g of soil and this was scattered on to the soil previously placed in the pots. The high dose vermicompost treatments received 38 g of vermicompost combined with soil. The fertiliser low dose pots received 12 mL of Ammonium Nitrate pipetted and combined with soil. Lastly, the higher dose fertiliser treatments received 24 mL per pot combined with soil. The treatments were arranged in lines according to soil type and left 48 hours to settle.

To measure the vermicompost effect at high additions, higher rates of vermicompost were applied to the Pine soil. The same process was repeated at vermicompost rates of 24, 36, 48, 60, 72 and 96 tonnes/ha. Each pot received perennial ryegrass seed, which was broadcasted over the pots. 50 grams of soil from each treatment was applied on top of the seed and the soils were transported to the Lincoln University Glasshouse (Figure 7). The pots were watered and covered by tinfoil to initiate germination and prevent the soils from drying out. After seedling germination, the tin foil was removed and the pots were watered every second day and monitored for weeds.

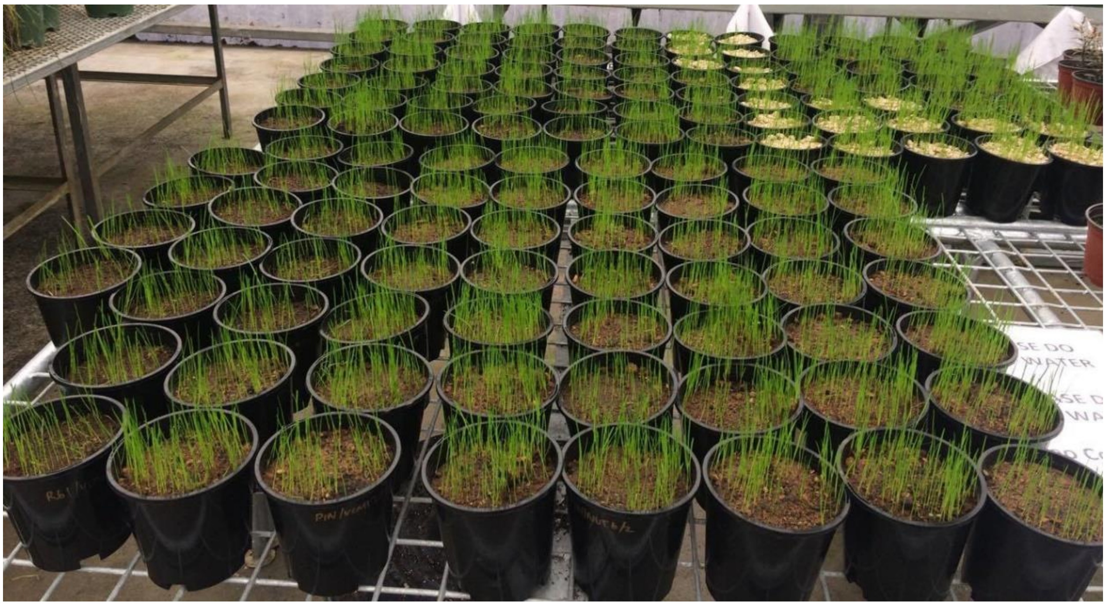


Figure 7. Pot trial in the Lincoln University Glasshouse.

3.2 Pasture sampling and analysis

The pots were harvested by cutting 2.5 cm above base level and each treatment was collected in a separate paper bag. The fresh weight samples were transported to the Field Service Centre and placed in the oven to dry for 48 hours. This was repeated five times, every three weeks to give pasture time to regenerate. The final harvest was completed on the 12^{th} of September and the pasture was cut to ground level. The replicates were combined for determination of total cumulative DM yield (mg/pot) and samples were analysed for total N, P, K, S to calculate nutrient uptake (mg/pot).

3.3 Data analysis

The ryegrass, vermicompost and soil sample results were retrieved from Hill Laboratories. The total nitrogen, phosphorus, potassium and sulphur contents were assessed in comparison to average yield of each treatment. For each treatment, differences in dry matter yield and nutrient composition were analysed for variance in GenStat. The means were then separated using Fisher's unprotected LSD test. This data was graphed using excel, for a visual representation of pasture dry matter yield. Lastly, the relative agronomic effectiveness [RAE = (VM-Control x 100)/(NUT12-Control)] was evaluated for differences in dry matter yield components for the six soils. The relative agronomic effectiveness was also calculated for total nitrogen, phosphorus, potassium and sulphur uptake for each soil (Table 12).

4. Results

4.1. Soil and Vermicompost analysis

The six soil samples were analysed for various soil properties (Table 5). There were large differences between the six soils. The dairy effluent soil had the highest fertility, whereas the control soil had the lowest soil fertility. There was a pH range of 5.6 to 6.5 across the six soils (mean = 5.89). Total carbon ranged from 0.1% to 8.3% (mean = 5.87%). Total nitrogen ranged from <0.04% to 0.79% (mean= 0.49%). Total mineralizable nitrogen (a measure of potentially plant available N) ranged from 2 to 63% (19.5%), Olsen P ranged from 2 mg/L to 130 mg/L (mean = 45 mg/L), sulphate sulphur ranged from 12 mg/kg to 43 mg/kg (mean = 18.17%) and total potassium ranged from 0.35 me/100g to 0.85 me/100g (mean = 0.58 me/100g).

Vermicompost as expected, contained high levels of nutrients (Table 7). The pH of the vermicompost was 7.4, the total carbon 12.2%, total nitrogen 1.17%, total phosphorus 6,100 mg/kg, total potassium 5.9 me/100g and total sulphur 3,230 mg/kg. Olsen P was high at 247 mg/L and sulphate sulphur was also high at 326 mg/kg. The anaerobically mineralisable nitrogen was 1.9%.

4.2. Plant yield and nutrient uptake

Table 10. Analysis of total DM yield (mg DM/pot) and nutrient uptake (%) in response to fertiliser and vermicompost (p value = indicates significance level of data, LSD = least significance between means and letters = means with the same letters are not significantly different, means with different letters are significant).

a. Control soil

	mg DM/pot	mg N/pot	mg P/pot	mg K/pot	mg S/pot
CON	258[a]	3.9[a]	0.4[a]	7.2[a]	0.5[a]
VM6	475[ab]	7.1[a]	1.3[b]	12.8[ab]	1.0[ab]
VM12	398[b]	6.0[a]	1.3[b]	11.5[b]	0.8[b]
NUT6	1135[c]	28.4[b]	4.5[c]	40.9[c]	4.0[c]
NUT12	1820[c]	41.9[c]	7.6[d]	51.0[d]	6.6[d]
p value	<0.01	<0.01	<0.01	<0.01	<0.01
LSD	178	3.36	0.57	5.51	0.48

b. Sheep finishing soil

	mg DM/pot	mg N/pot	mg P/pot	mg K/pot	mg S/pot
CON	823[a]	18.1[a]	2.2[a]	12.3[a]	3.0[a]
VM6	1090[a]	22.9[a]	3.7[b]	19.6[b]	4.0[ab]
VM12	1105[a]	23.2[a]	3.9[b]	19.9[b]	4.2[b]
NUT6	1870[b]	54.2[b]	6.0[c]	22.4[bc]	6.9[c]
NUT12	2338[c]	77.1[c]	7.5[d]	25.7[c]	8.7[d]
p value	<0.01	<0.01	<0.01	<0.01	<0.01
LSD	311	8.18	0.97	4.54	1.14

c. Sheep new soil

	mg DM/pot	mg N/pot	mg P/pot	mg K/pot	mg S/pot
CON	1165[a]	21.0[a]	4.0[a]	35.0[a]	4.2[a]
VM6	1188[a]	26.1[ab]	4.6[b]	40.3[b]	4.5[a]
VM12	1250[a]	25.0[b]	5.1[b]	36.3[b]	4.9[a]
NUT6	1953[b]	56.6[c]	6.6[c]	56.6[c]	7.6[b]
NUT12	2470[c]	61.8[d]	7.4[d]	59.3[d]	8.9[c]
p value	<0.01	<0.01	<0.01	<0.01	<0.01
LSD	195.0	4.75	0.66	0.67	0.73

d. Dairy effluent soil

	mg DM/pot	mg N/pot	mg P/pot	mg K/pot	mg S/pot
CON	1490[a]	31.3[a]	5.7[a]	37.3[a]	4.0[a]
VM6	1525[a]	30.5[a]	6.0[a]	41.2[ab]	4.4[a]
VM12	1480[a]	32.6[a]	6.5[a]	47.4[bc]	4.4[a]
NUT6	2283[b]	57.1[b]	8.9[b]	54.8[cd]	7.1[b]
NUT12	2953[c]	79.7[c]	11.2[c]	62.0[d]	10.3[c]
p value	<0.01	<0.01	<0.01	<0.01	<0.01
LSD	345	7.86	1.35	8.86	1.02

e. Dairy new soil

	mg DM/pot	mg N/pot	mg P/pot	mg K/pot	mg S/pot
CON	1248[a]	23.7[a]	5.1[a]	36.2[a]	4.5[a]
VM6	1345[a]	24.2[a]	5.8[b]	39.0[a]	4.6[a]
VM12	1370[a]	26.0[a]	5.9[b]	38.4[a]	4.8[a]
NUT6	2085[b]	48.0[b]	8.6[c]	43.8[b]	8.1[b]
NUT12	2420[c]	60.5[c]	10.4[d]	46.0[b]	9.7[c]
p value	<0.001	<0.01	<0.01	<0.01	<0.01
LSD	157.4	3.38	0.67	3.96	0.59

f. Pine soil

	mg DM/pot	mg N/pot	mg P/pot	mg K/pot	mg S/pot
CON	473[a]	6.6[a]	0.5[a]	11.3[a]	1.0[a]
VM6	548[a]	8.2[ab]	1.2[b]	15.3[b]	1.4[ab]
VM12	620[a]	9.9[b]	1.8[c]	18.6[b]	1.7[b]
NUT6	1415[b]	32.6[c]	3.5[d]	32.6[c]	5.2[c]
NUT12	2108[c]	52.7[d]	5.3[e]	42.2[d]	7.6[d]
p value	<0.01	<0.01	<0.01	<0.01	<0.01
LSD	149	3.24	0.36	3.51	0.5

Table 11. Analysis of total DM yield (mg DM/pot) and nutrient uptake (%) in response to high rates of vermicompost in the pine soil (p value = indicates significance level of data, LSD = least significance between means and letters = means with the same letters are not significantly different, means with different letters are significant).

	mg DM/pot	mg N/pot	mg P/pot	mg K/pot	mg S/pot
CON	473^{a}	6.6^{a}	0.5^{a}	11.3^{a}	1.0^{a}
VM6	548^{a}	8.2^{ab}	1.2^{b}	15.3^{b}	1.4^{ab}
VM12	620^{a}	9.9^{b}	1.8^{c}	18.6^{b}	1.7^{b}
VM24	655^{a}	11.1^{a}	2.4^{a}	21.0^{a}	2.1^{a}
VM36	758^{ab}	11.4^{a}	2.7^{ab}	22.7^{ab}	2.4^{a}
VM48	830^{b}	13.3^{ab}	3.2^{bc}	26.6^{bc}	2.6^{ab}
VM60	900^{bc}	14.4^{b}	3.8^{cd}	29.7^{c}	2.9^{bc}
VM72	893^{bc}	14.3^{b}	3.7^{cd}	28.6^{c}	3.0^{bc}
VM96	1020^{c}	15.3^{b}	4.3^{d}	30.6^{c}	3.4^{c}
NUT6	1415^{b}	32.6^{c}	3.5^{d}	32.6^{c}	5.2^{c}
NUT12	2108^{c}	52.7^{d}	5.3^{e}	42.2^{d}	7.6^{d}
p value	<0.01	0.01	<0.01	<0.01	<0.01
LSD	162	1.19	0.65	4.99	0.53

Data for all six soils showed that dry matter yield and nutrient uptake increased in response to the addition of soluble nutrients (NUT6, NUT12) and vermicompost (VM6, VM12). Although, the level of response varied between soils, in most cases highest dry matter yield and corresponding nutrient uptake were observed in response to additions of soluble nutrients at the high rate (NUT12), while a proportional response occurred to the addition of nutrients at the lower rates (NUT6). However, the dry matter yield and nutrient uptake responses to vermicompost addition were significantly lower compared with the equivalent soluble nutrient additions, especially for dry matter yield, nitrogen uptake and sulphur uptake. The dairy effluent soil obtained the highest DM yield response (mean = 1946.2 mg DM/pot) whereas lowest DM yields were found in the control soil (mean= 681 mg DM/pot).

For the Pine soil, dry matter yield and nutrient uptake increased in response to the addition of vermicompost up to 96 tonnes per hectare. However, dry matter yield and nitrogen uptake remained significantly low compared with soluble nutrient inputs. Whereas, uptake of phosphorus, potassium and sulphur were similar for inputs of 96 tonnes per hectare of vermicompost and soluble nutrients added at the equivalent of 6 tonnes per hectare (NUT6).

4.3. Relative Agronomic Effectiveness

Table 12. Relative agronomic effectiveness (%) data for dry matter yield and nutrient uptake for all six soils compared with NUT12. Relative Agronomic effectiveness = [(VM-Control x 100)/(NUT12-Control)].

a. Total dry matter

Treatments	Control	Dairy Effluent	Dairy new	Sheep finishing	Sheep new	Pine	overall mean
VM6	14	2	8	18	2	5	8
VM12	9	-1	10	19	7	9	9
NUT6	56	54	71	69	60	58	61

b. Total nitrogen

Treatments	Control	Dairy Effluent	Dairy new	Sheep finishing	Sheep new	Pine	overall mean
VM6	9	0	1	8	13	3	6
VM12	6	3	6	9	10	7	7
NUT6	65	53	66	61	83	56	64

c. Total phosphorus

Treatments	Control	Dairy Effluent	Dairy new	Sheep finishing	Sheep new	Pine	overall mean
VM6	13	5	13	28	19	14	16
VM12	13	15	15	31	34	27	22
NUT6	57	58	65	71	78	64	66

d. Total potassium

Treatments	Control	Dairy Effluent	Dairy new	Sheep finishing	Sheep new	Pine	overall mean
VM6	13	16	29	54	22	13	25
VM12	10	41	22	56	5	24	26
NUT6	77	71	78	76	89	69	76

e. Total sulphur

Treatments	Control	Dairy Effluent	Dairy new	Sheep finishing	Sheep new	Pine	overall mean
VM6	8	6	2	19	7	6	8
VM12	6	7	6	22	15	11	11
NUT6	58	48	70	70	61	64	62

Table 13. Relative agronomic effectiveness (%) data for dry matter yield and nutrient uptake for Pine soil compared with NUT12. Relative Agronomic effectiveness = [(VM-Control x 100)/(NUT12-Control)].

	DM yield	Total N	Total P	Total K	Total S
VM6	5	3	14	13	20
VM12	9	7	27	24	28
VM24	11	10	39	31	16
VM36	17	10	47	37	20
VM48	22	14	57	49	23
VM60	26	17	69	60	28
VM72	26	17	66	56	29
VM96	33	19	79	63	36
NUT6	58	56	64	69	28

The relative agronomic effectiveness data highlighted the poor agronomic performance of vermicompost at 6 and 12 tonnes per hectare compared with soluble nutrients. This was especially the case for dry matter yield (8-9%), nitrogen uptake (6-7%) and sulphur uptake (8-11%). On the other hand, higher plant uptake of phosphorus (16-22%) and potassium (25-26%) occurred in response to vermicompost application. These trends were confirmed for higher rates of vermicompost input to the Pine soil (Table 13). Thus, dry matter yield only increased 33% at 96 tonnes per hectare of vermicompost, while nitrogen and sulphur only increased 19% and 36%, respectively, at the highest rate. However, higher nutrient uptake of phosphorus (79%) and potassium (63%) were observed at highest vermicompost rates.

5. Discussion

5.1 Agronomic effectiveness of vermicompost compared with soluble nutrients across six soils

The purpose of this study was to assess the ability of vermicompost to supply nitrogen, phosphorus, potassium and sulphur to perennial ryegrass on six different soils. Despite the range of soils and experimental approach used, it was clear from this study, the Tuaropaki vermicompost was not a good short-term source of nutrients for perennial ryegrass. This was particularly evident for nitrogen and sulphur uptake, while the uptake of phosphorus and potassium were higher.

This suggests the nutrients were present in forms which were not immediately available for uptake, especially for nitrogen and sulphur. However, this study only gives an assessment of relative soluble nutrients over a short time. The nutrients may become available overtime, providing a slow release of nutrients to plants. This was consistent with findings reported by Kizilkaya et al. (2002) who found vermicompost acted as a slow release fertiliser, supplying the soil and plants with valuable nutrients.

The relative agronomic effectiveness for dry matter yield was relatively poor compared to the uptake of phosphorus and potassium. The relative agronomic effectiveness for dry matter yield only slightly increased when vermicompost increased from 6 t/ha to 12 t/ha (mean = 8% vs. 9%). This could have been associated with nutrients being held in organic form during the trial, which rendered the nutrients unavailable for plant uptake. Consequently, the yield response was limited. In contrast, the high fertiliser rate (NUT12) contained 100% water soluble nutrients, thus the yield response was more evident. The relative agronomic effectiveness was considerably higher in the sheep finishing soil, whereas the dairy effluent soil stood out as the lowest scores. The dairy effluent soil could have had the lowest relative agronomic effectiveness due to the high pre-existing soil fertility (Table 5). This would have caused no real yield benefit of applying the vermicompost as the nutrients all existed in the soil at high rates previously. Whereas, the sheep finishing soil, had lower pre-existing soil fertility, which encouraged higher plant uptake and yielding in response to nutrients previously deficient in the soil. The greater the deficit of nitrogen in soil, the higher the DM yield response and nutrient uptake (Dairy NZ, 2012).

The relative agronomic effectiveness for total nitrogen was minor with vermicompost applied at 6 t/ha and 12 t/ha (mean = 6% and 7%). In contrast, soluble nutrients applied at the similar rate (NUT6) showed a considerably higher relative agronomic effectiveness (64%). Application of soluble nutrients allowed 100% inorganic nitrogen application, available for plant uptake. Although, the anaerobically mineralisable nitrogen (as a measure of potentially mineralizable nitrogen) was 227 µg/g for vermicompost (Table 7), which represented only 2% of total nitrogen. This indicated that most of the nitrogen in vermicompost was present in organic form. Thus, majority of the nitrogen present in the vermicompost would have not been readily broken down. Concentration of plant available ammonium is typically low in soils, as it's readily converted to nitrate (NO3-) and subsequently prone to leaching (Di & Cameron, 2002). Therefore, the yield response would have been constrained with lower available nitrogen applied. The relative agronomic effectiveness was 0 for total nitrogen in the VM6 treatment Dairy effluent soil. This was potentially due to the high amount of available nitrogen which already existed in the soil (236 µg/g), which would have restricted the response to vermicompost treatment.

The relative agronomic effectiveness of total phosphorus was high with vermicompost application (mean 16% VM6 and mean 22% VM12). The Olsen P contained in the vermicompost was 247 mg/L and the total phosphorus equated to 6,100 mg/kg, which means that plant available Olsen P only accounted for 7% of total P in vermicompost. This was consistent with other research, as most of soil phosphorus (90-95%) is present in inorganic and organic forms which are not available for plant uptake (Perez et al. 1996). However, there was a high uptake of phosphorus in each treatment once the vermicompost was applied. The high relative agronomic effectiveness of phosphorus uptake could be related to the vermicompost source. The vermicompost sourced from Tuaropaki comprised of green waste material, dairy manure and DAF sludge. The DAF sludge is an off product from milk processing, thus, this may have released more calcium phosphate into the vermicompost. This accelerated plant yield response, as indicated by the relative agronomic effectiveness. High yield responses from available P were consistent with other vermicompost trials. Kizilkaya et al. (2012) found an increase in available phosphorus in straw from 0.06% (control) to 0.28% (vermicompost applied), which in turn encouraged a higher yield of wheat.

The relative agronomic effectiveness of total potassium was high with vermicompost application (mean 25% VM6 and 26% VM12). The highest response was observed in the sheep finishing soil. The amount of available potassium in vermicompost was not determined. Thus, it was difficult to predict how much of available potassium was applied. It was assumed a high amount of potassium was present in the vermicompost as it contained dairy manure. This would have increased potassium levels which was evident in the relative agronomic effectiveness of potassium uptake. This was consistent with Antoniadis et al. (2016) who showed that uptake of potassium increased from 56 kg K_2O ha^{-1} to 74 kg K_2O ha^{-1} once manure was applied compared to the control.

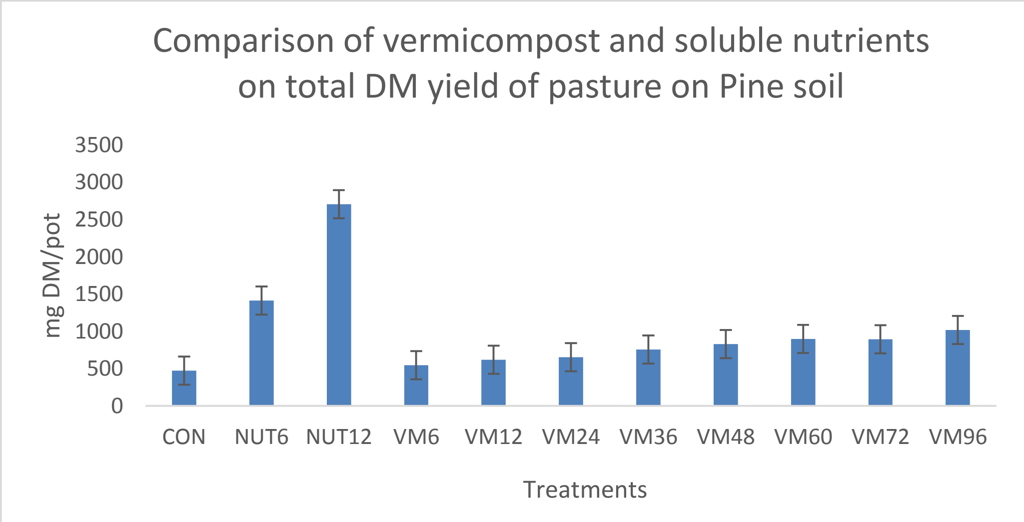
The relative agronomic effectiveness of total sulphur was low with vermicompost application (mean 8% VM6 and 11% VM12). The amount of total sulphur contained in the vermicompost was 3,230 mg/kg with the sulphate sulphur recorded as 326 mg/kg, thus plant available sulphur represented

10% of the total sulphur present. The sulphur was likely to have been tied up mainly in organic forms, thus plants were unable to access this, which would have restricted yield response.

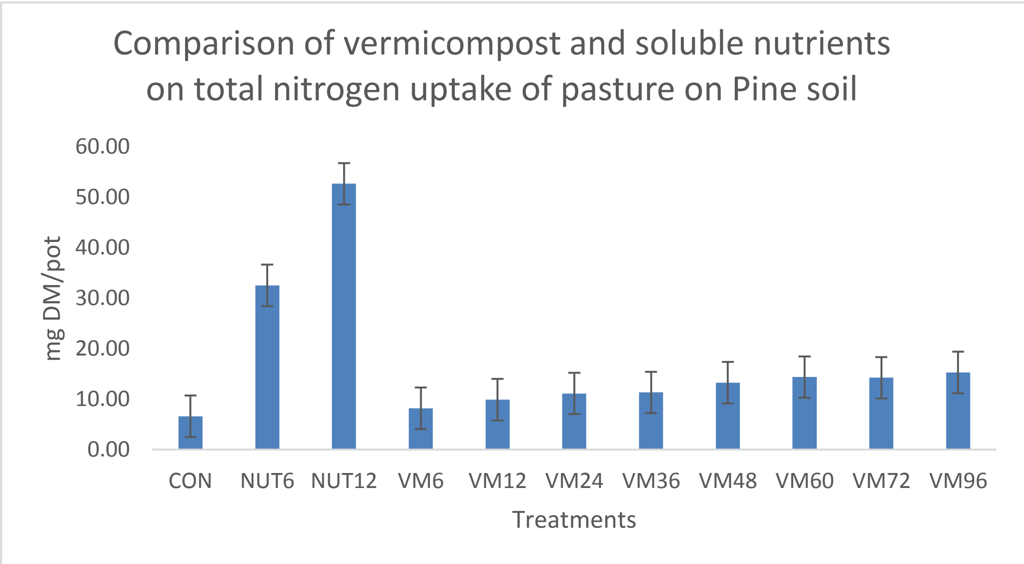
The relative agronomic performance across the six different soils was very similar despite the soils large range in soil fertility. This suggested, the nutrient supplying ability was determined by vermicompost composition rather than soil conditions. The composition of the Tuaropaki vermicompost restricted the short-term availability of nutrients. Whereas, Arancon (2012) applied vermicompost extracts and found the higher nutrient availability enhanced germination of tomato and lettuce seedlings.

5.2 Agronomic effectiveness of vermicompost at high rates of additon.

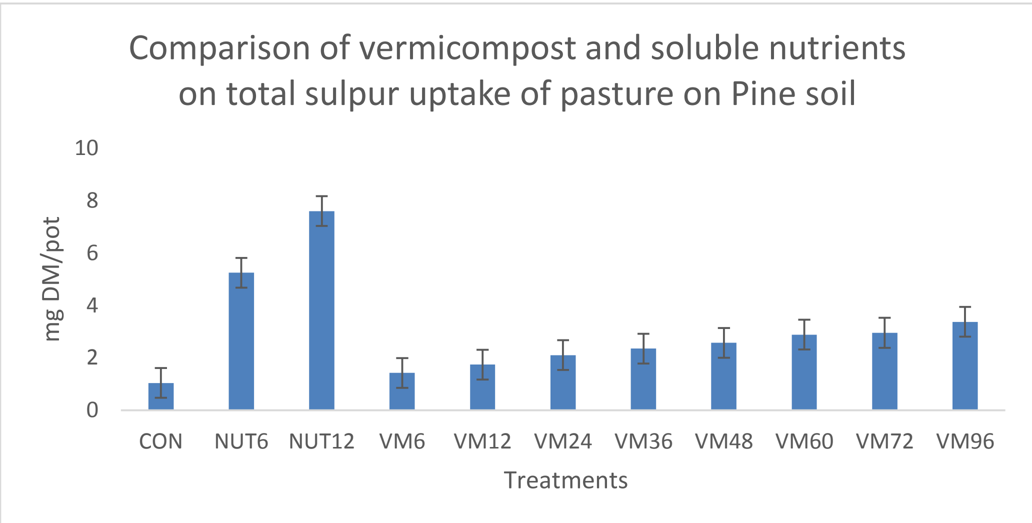
The relative agronomic effectiveness for dry matter yield and nutrient availability slightly increased in the pine soil when higher rates of vermicompost were applied. Vermicompost applied at higher rates, up to 96 tonnes per hectare, had little impact on total yield (Figure 8).



a. Dry matter yield



b. Nitrogen uptake.



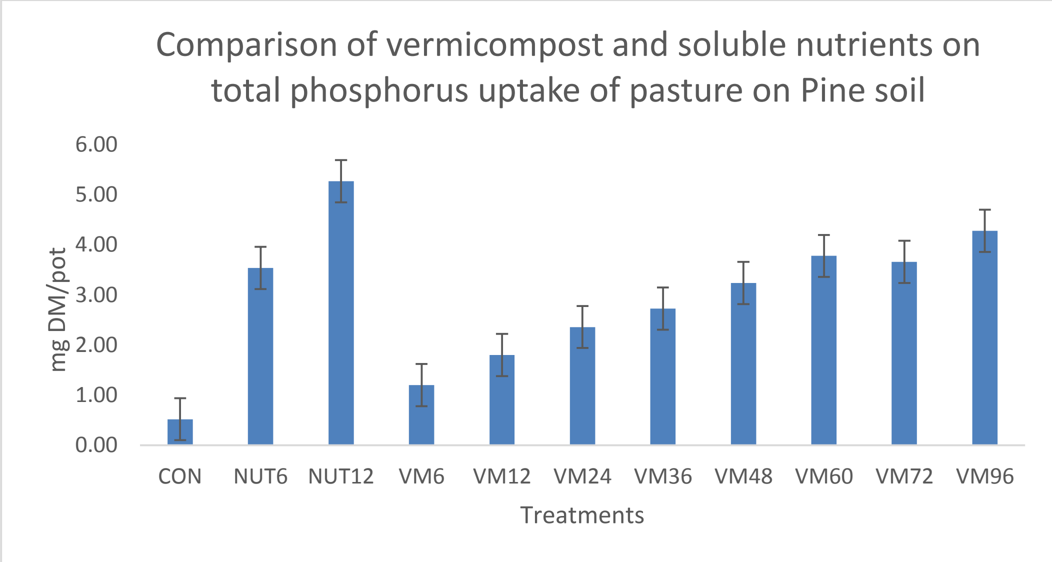
c. Sulphur uptake.

Figure 8. Comparison of vermicompost and soluble nutrients on total dry matter yield of pasture and nitrogen and sulphur uptake on pine soil. (Error bars: standard error of the mean).

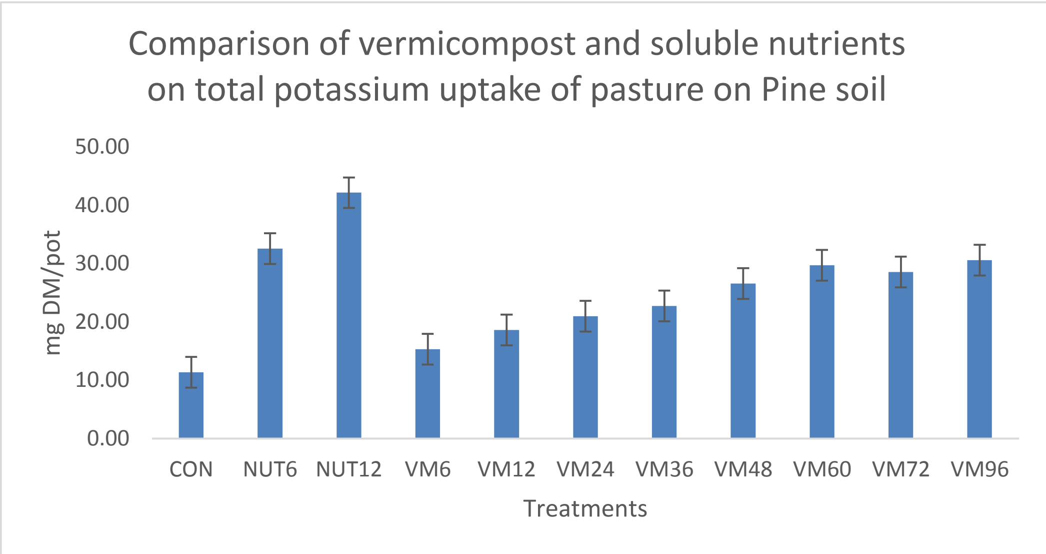
Overall, there were very similar trends for nitrogen and sulphur uptake. The vermicompost response was limited, confirming that the short-term plant availability of nitrogen and sulphur in Tuaropaki vermicompost was very limited.

The DM yield response was lowest in the control treatment and significantly higher in the highest fertiliser application treatment (NUT12). This was due to the fact, the nutrients were 100% water soluble, which rendered a higher yield response. The total yield reached 1020 mg DM/pot in the VM96 compared to 548 mg DM/pot in the VM6 treatment.

There was a low uptake of nitrogen, even when the vermicompost was increased up to 96 tonnes per hectare. This highlighted the low short-term nutrient availability of vermicompost. The sulphur response was also low for increased vermicompost application. The low sulphur and nitrogen uptake from vermicompost addition was likely to be linked to these nutrients being present in organic form. However, this may have great implications for the environment as leaching may be reduced where N and S aren't present in the soil at high amounts. Nitrate (NO_3-) and sulphate (SO_4) are cations which are highly vulnerable to leaching (McLaren & Cameron, 2012). Thus, vermicompost may provide an environmental benefit of reducing these losses while providing longer term benefits in plant yield. Further research should explore the implications of using vermicompost to mitigate leaching.



a. Phosphorus uptake



b. Potassium uptake

Figure 9. Comparison of vermicompost and soluble nutrients on total phosphorus and potassium uptake of pasture on pine soil. (Error bars: standard error of the mean).

Similarly, data for phosphorus and potassium uptake showed that plant uptake increased steadily with increasing application of vermicompost. There was a notable increase in the relative agronomic effectiveness for phosphorus content (79%) when vermicompost was applied at 96 t/ha. . Potassium uptake increased from 11.34 mg K/pot (CON) to 30.6 mg K/pot. These trends confirm the improved plant availability of phosphorus and potassium in Tuaropaki vermicompost compared with nitrogen and sulphur. This in turn may be attributed to the fact that most of the nitrogen and sulphur in the vermicompost was present in stable organic form which were resistant to mineralisation in the short term.

6. Conclusions

The objective of this trial was to assess and quantify the agronomic value of vermicompost applied to six different soils with respect to perennial ryegrass uptake of applied nitrogen, phosphorus, potassium and sulphur. The findings of this study clearly demonstrated that Tuaropaki vermicompost was a relatively poor short-term source of major nutrients for perennial ryegrass compared with nutrients added in water soluble form. This was especially evident for nitrogen and sulphur which may be attributed to the predominance of stable organic forms of these nutrients in the vermicompost. On the other hand, the plant availability of phosphorus and potassium in vermicompost were greater than what was observed for nitrogen and sulphur. This may reflect differences in the forms of these nutrients, and the predominance of inorganic phosphorus and potassium, whose ability is determined by chemical solubility.

It is possible that the Tuaropaki vermicompost could be a viable long-term slow-release nutrient source in soil. These trends were confirmed for one soil (Pine) by the addition of increased quantities of vermicompost, up to 96 tonnes per hectare. The results of this research clearly indicate that Tuaropaki vermicompost is potentially a good slow release nutrient source, which could also be used as a soil conditioning agent for the restoration of degraded or nutrient depleted soil.

References

Antoniadis, V., Koutroubas, D. & Fotiadis, S. (2015). Nitrogen, Phosphorus, and Potassium Availability in Manure- and Sewage Sludge-Applied Soil. *Communications in Soil Science and Plant Analysis. 3,* 393-404.

Arancon, N. Q. (2012). Seed germination and seedling growth of tomato and lettuce as affected by vermicompost water extracts (teas). *HortScience, 47*(12), 1722-1728.

Atiyeh, R. M., Arancon, N., Edwards, C.A. Metzger, J. D. (2000). Influence of earthworm processed pig manure on the growth and yield of greenhouse tomatoes. *Bio resource Technology, 1*(75), 175-180.

Azarmi, R., Giglou, M. T., Taleshmikail, R. D. (2009). Influence of vermicompost on soil chemical and physical properties in tomato (Lycopersicum esculentum) field. *African Journal of Biotechnology, 14,* 2397-2401.

Bajracharya, S. K., Sercahn, D. P. & Bhattarai, S. (2007). Effect of Vermicompost in Combination with Bacterial and Mineral Fertilizers on the Yield of Vegetable Soybean. *Korean Journal of Crop Science, 52*(1), 100-103.

Cameron, K. C., Di, H. J. & Moir, J. L. (2012). Nitrogen losses from the soil/plant system: a review. *Annals of Applied Biology,* 145-173.

Chavda, V. N. & Rajawat, B. S. (2015). Performance evaluation of vermicompost on yield of Kharif groundnut and cotton crops*. International Journal of Forestry and Crop Improvement. 6*(2), 127-131.

Condron, L. (2017). The Marvel of Soil Biodiversity. *New Zealand Turf Management Journal*, 24-25.

Dairy NZ. (2012). *Seasonal nitrogen use*. Retrieved from https://www.dairynz.co.nz/media/255711/7-11_Seasonal_nitrogen_use_2012

Di, H. J., Cameron, K. C. (2000). Calculating nitrogen leaching losses and critical nitrogen application rates in dairy pasture systems using a semi-empirical model. *New Zealand Journal of Agricultural Research*, *43*, 139-147.

Di, H. J., Cameron, K. C. (2002). Nitrate leaching in temperate agroecosystems: sources, factors and mitigating strategies. *Nutrient cycling in Agroecosystems, 46,* 237-256.

Dodd, M. B. & Mackay, A. D. (2011). Effects of contrasting soil fertility on root mass, root growth, root decomposition and soil carbon under a New Zealand perennial ryegrass/white clover pasture. *Plant and Soil, 349*, 291-302.

Edwards, A. C., Arancon, N. Q., Bennett, M. V., Askar, A., Keeney, G. & Little, B. (2010). Suppression of green peach aphid (Myzus persicae) (Sulz.), citrus mealybug (Planococcus citri) Risso), and two spotted spider mites (Tetranychus urticae) (Koch.) attacks on tomatoes and cucumbers by aqueous extracts from Vermicomposts. *Crop Protection, 1*(29), 80-93.

Griffiths, B. S. (1986). Mineralization of nitrogen and phosphorus by mixed cultures of the ciliate protozoan *Colpoda steinii*, the nematode *Rhabditis SP*. and the bacterium Pseudomonas fluorescents. *Soil Biology and Biochemistry, 18*(6), 637-641.

Guo, L., Wu, G., Li, C., Liu, W., Yu, X., Cheng, D. & Jiang, G. (2015). Vermicomposting with maize increases agricultural benefits by 304%. *Agronomy for Sustainable Development, 3*(35), 1149-1155.

Hossein, K., Mokhtari, M., Salehi, F., Sojoudi, S., & Ebrahimi, A. (2017). Changes in microbial pathogen dynamics during vermicomposting mixture of cow manure-organic solid waste and cow manure- sewage sludge. *International Journal of Recycled Organic Waste Agriculture, 6*(1) 57-61.

Ievinsh, G. (2011). Vermicompost treatment differentially affects seed germination, seedling growth and physiological status of vegetable crop species. *Plant Growth Regulation, 65(*1) 169-181.

Joshi, R., Singh, J. & Vig, A. P. (2015). Vermicompost as an effective organic fertilizer and biocontrol agent: effect on growth, yield and quality of plants. *Environment science biotechnology, 1*(14), 137 -159.

Kizilkaya, R., Turkay, F. S., Turkmen, C. & Durmus, M. (2012). Vermicompost effects on wheat yield and nutrient contents in soil and plant. *Archives of Agronomy and Soil Science, 1*(58), 175-179.

Lazcano, C., Gomez, M., & Dominguez, J. (2008). Comparison of the effectiveness of composting and vermicomposting for the biological stability of cattle manure. *Chemosphere, 72*(7), 1013-1019.

Lehmeier, C. A., Wild, M. & Schnyder, H. (2013). Nitrogen stress affects the turnover and size of nitrogen pools supplying leaf growth in a grass. *Plant Physiology*, *162*, 2095-2105.

Masciandaro, G., Macci, C., Doni, S. & Caccanti, B. (2010). Use of earthworms (*Eisenia fetida*) to reduce phytotoxicity and promote humifaction of pre-composted olive oil mill wastewater. *Wiley Interscience, 2*(90), 1879-1885.

McLaren, R.G., Cameron, K. (2012). Water and solute movement in soils and plants (Chapter 7). In: *Soil Science: Sustainable Production and Environmental Protection.* Pages 87-104. Auckland: Oxford University Press.

Nidoni, P., & Math, P. (2015). Solid Waste Management by Vermicomposting Process. *Indian Journal of Science Research, 12(*1), 192-196.

Orgiazzi, A., Bardgett, R. D., Barrios, E., Behan-Pelletier, V., Briones, M.J. (2016). *Global Soil Biodiversity Atlas.* Luxembourg: European Commission.

Papathanasiou, F., Papadopoulos, I., Tsakiris, I. & Tamoutsidis, E. (2012). Vermicompost as a soil supplement to improve growth, yield and quality of lettuce (Lactuca sativa L.). *Journal of Food, Agriculture and the Environment, 10,* 677-682.

Parfitt, R. L., Yeates, G. W., Ross, D. J., Mackay, A. D. & Budding, P. J. (2004). Relationships between soil biota, nitrogen and phosphorus availability and pasture growth under organic and conventional management. *Applied Soil Ecology, 28*(1), 1-13.

Perez, M. E., Klundert, I. & Verhoeven, J. T. (1996). Availability of organic and inorganic phosphorus compounds as phosphorus sources for *Carex* species. *New Phytology, 133*, 225-231.

Peyvast, G. H. (2008). Vermicompost as a Soil Supplement to Improve Growth and Yield of Parsley. *International Journal of Vegetable Science, 14*, 82-92.

Planet Natural Research. (2012). Worm composting 101: The Dirty Truth About Vermicomposting. Retrieved from: https://www.planetnatural.com/worm-composting/

Sabrina, D. T., Hanafi, M. M., Gandahi, A. W., Muda Mohamed, M. T. & Abdul Aziz, N. A. (2013). Effect of mixed organic-inorganic fertilizer on growth and phosphorus uptake of setaria grass (*Setaria splendida). Australian Journal of Crop Science, 7,* 75-83.

Singh, R. P., Singh P., Araujo, S. F., Ibrahim, M. H, & Sulaiman, O. (2011). Management of urban solid waste: Vermicomposting a sustainable option. Resources, *Conservation and Recycling, 55*(1), 719-729.

Singh, S., Singh, J., & Pal Vig, A. (2016). Earthworm as ecological engineers to change the physio-chemical properties of soil: Soil vs vermicast. *Ecological Engineering, 90*(1) 1-5.

Suthar, S. (2009). Impact of vermicompost and composted farm manure on growth and yield of garlic *(Allium stivum L.)* field crop. *International Journal of Plant Production, 3,* 155-161.

Tejada, M., & Gonzalez, J. L. (2009). Application of Two Vermicomposts on a Rice Crop: Effects on Soil Biological Properties and Rice Quality and Yield. *Agronomy Journal, 2*(101), 336-344.

Uma, B. & Malathi, M. (2009). Vermicompost as a soil supplement to improve growth and yield of *Amaranthus* species. *Resource Journal of Agriculture and Biological Science, 6,* 1054-1060.

Yadav, S., & Singh, V.K. (2014). *Vermitechnology: Rebuilding Sustainable Rural Livelihoods.* New York: Nova Science Publishers.

Appendix A

Soil and vermicompost analysis

A.1 Chemical and physical properties of the six Tuaropaki soils.

Test results by Hill Laboratories

Analysis	Measure		Dairy Effluent (Paddock)	Dairy Effluent (Strip Trial Area)	Dairy New (Paddock)	Dairy New (Strip Trial Area)	Farm Finishing (Paddock)	Farm Finishing (Strip Trial Area)	Farm New (Paddock)	Farm New (Strip Trial Area)	Pine Cutover
		Level Found									
pH	pH Units	5.9	6.5	6.6	5.6	5.4	5.9	5.9	5.7	5.6	5.7
Olsen Phosphorus	mg/L	2	64	79	130	163	21	13	51	29	2
Anion Storage Capacity (estimated)	%	< 15	31	30	30	31	39	35	48	52	70
Potassium	me/100g	0.63	0.71	1.21	0.60	0.67	0.31	0.20	0.85	0.76	0.35
Calcium	me/100g	< 0.5	18.7	21.5	5.1	6.1	11.2	10.4	8.1	7.5	1.3
Magnesium	me/100g	< 0.04	2.43	2.55	0.59	0.57	1.03	0.71	1.56	1.40	0.24
Sodium	me/100g	0.07	0.30	0.22	0.13	0.09	0.20	0.14	0.09	0.10	0.07
Potassium	%BS	21.9	2.6	4.3	3.5	3.3	1.3	1.0	3.4	3.2	3.0
Calcium	%BS	10	67	76	29	30	47	51	33	31	11
Magnesium	%BS	1.1	8.8	9	3.4	2.7	4.3	3.5	6.3	5.9	2.1
Sodium	%BS	2.3	1.1	0.8	0.7	0.5	0.9	0.7	0.3	0.4	0.6
CEC	me/100g	3	28	28	17	21	24	20	25	24	12
Total Base Saturation	%	35	80	90	37	36	53	56	43	41	17
Volume Weight	g/mL	0.76	0.54	0.54	0.70	0.63	0.54	0.62	0.53	0.55	0.65
Sulphate Sulphur	mg/kg	12	12	11	13	17	14	12	15	19	43
Extractable Organic Sulphur	mg/kg	< 2	8.0	7.0	5.0	6.0	5.0	5.0	6.0	4.0	4.0
Soluble Salts (Field)	%	< 0.05	< 0.05	0.08	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
EC (in 1:5 Extract)	mS/cm	< 0.01	0.14	0.22	0.03	0.05	0.04	0.05	0.05	0.05	< 0.01
Potentially Available N (15cm Depth)	kg/ha	14	190	223	179	217	186	174	106	97	28
Anaerobically Mineralisable N	µg/g	13	236	274	171	231	231	187	133	117	29
Ammonium-N	mg/kg	1	23	16	4	4	11	26	4	3	2
Nitrate-N	mg/kg	< 1	41	71	7	10	7	5	16	12	1
Mineral N (sum)	mg/kg	2	63	87	11	15	18	31	20	15	3
Organic Matter	%	0.2	14.4	16.2	13.3	15.9	14.3	13.8	12.9	13.8	5.6
Total Carbon	%	0.1	8.3	9.4	7.7	9.2	8.3	8.0	7.5	8.0	3.3
Total N	%	< 0.04	0.79	0.88	0.61	0.79	0.72	0.67	0.53	0.47	0.22

A.2 Analysis of Tuaropaki vermicompost as a soil sample.

Sample Type: COMPOST, General		
Water extractable Results	**Measure**	**Actual value**
pH	pH Units	7.6
Electrical conductivity (EC)	mS/cm	0.8
Nitrate-N	mg/L	22
Ammonium-N	mg/L	1
Phosphorus	mg/L	5
Potassium	mg/L	132
Sulphur	mg/L	51
Calcium	mg/L	21
Magnesium	mg/L	5
Sodium	mg/L	42
Total Analysis Results - Dry Weight Basis		
Organic matter	%	30.1
Total Carbon	%	17.5
Total Nitrogen	%	1.36
C/N Ratio	%	12.8
Dry Matter	%	41.6
Total Phosphorus	mg/kg	6,340
Total Phosphorus	%	0.63
Total Sulphur	mg/kg	3,150
Total Sulphur	%	0.32
Total Potassium	mg/kg	2,930
Total Potassium	%	0.29
Total Calcium	mg/kg	26,400
Total Calcium	%	2.64
Total Magnesium	mg/kg	2,830
Total Magnesium	%	0.28
Total Sodium	mg/kg	924
Total Sodium	%	0.09
Total Iron	mg/kg	5,000
Total Manganese	mg/kg	380
Total Zinc	mg/kg	118
Total Copper	mg/kg	44

A.3 Chemical properties of Tuaropaki vermicompost

Analysis		Level Found	Medium Range
pH	pH Units	7.4	5.8 - 6.2
Olsen Phosphorus	mg/L	247	20 - 30
Potassium	me/100g	5.90	0.40 - 0.60
Calcium	me/100g	43.2	4.0 - 10.0
Magnesium	me/100g	7.72	1.00 - 1.60
Sodium	me/100g	1.91	0.20 - 0.50
CEC	me/100g	59	12 - 25
Total Base Saturation	%	100	50 - 85
Volume Weight	g/mL	0.57	0.60 - 1.00
Sulphate Sulphur	mg/kg	326	10 - 12
Potentially Available Nitrogen (15cm Depth)*	kg/ha	195	150 - 250
Anaerobically Mineralisable N*	µg/g	227	
Organic Matter*	%	21.1	7.0 - 17.0
Total Carbon*	%	12.2	
Total Nitrogen*	%	1.17	0.30 - 0.60
C/N Ratio*		10.5	
Anaerobically Mineralisable N/Total N Ratio*	%	1.9	3.0 - 5.0
'Total' Phosphorus	mg/kg	6,100	700 - 1600
'Total' Sulphur	mg/kg	3,230	600 - 1000
Base Saturation %		K 10.0 Ca 74	Mg 13.1 Na 3.2
MAF Units		K 69 Ca 31	Mg 100 Na 50